RESISTANCE SPOT WELDING OF STAINLESS STEEL AND MILD STEEL

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ABSTRACT

Resistance spot welding (RSW) is commonly used in manufacturing and automotive industry; because of their advantages such as high speed and high production, suitability for automation, easily to process and low cost. This project deals with the investigation of microstructure and mechanical properties of weld joint of Stainless Steel and Mild Steel. The main objective of this project is to investigate the weldability of stainless steel and steel weld. For design of experiment, Taguchi method was employed by using Minitab software, and total nine (9) sets experiment was conducted. The studies of mechanical properties, are consists by using three (3) tests; Tensile test, Charpy test, and microstructure to analyze and investigate the weldability of Stainless Steel and Mild Steel sheet. As a result, higher Tensile strength and Charpy toughness is due to increase in width and depth of weld nugget. Optimum specimen has higher width and depth than experimental specimen. Based on Taguchi analysis, the best combination of parameters is Current (5.0 kA), Weld Time (3.0 cycle) and Pressure (40 psi). The rank of parameter affected the resistance spot welding experiment is Current, Pressure and Weld Time respectively. Based on Regression analysis, the equation of Tensile strength and Charpy toughness were generated. As for recommendation, the other parameters such as diameters of electrode and hold time can be added in experiment. For conclusion, Taguchi analysis is verified with verification experiment.

ABSTRAK

Kimpalan rintangan bintik biasanya digunakan dalam industri pembuatan dan automotif; kerana kelebihan kimpalan ini seperti kelajuan yang tinggi dan hasil pengeluaran yang tinggi, kesesuaian untuk automasi, mudah diproses dan berkos rendah. Projek ini berkait dengan pengkajian tentang mikrostruktur dan ciri-ciri mekanikal logam kimpalan yang menggabungkan “keluli tahan karat” dan “keluli lembut”. Objektif utama projek ini ialah untuk mengkaji kebolehan kimpalan diantara “keluli tahan karat” dan “keluli lembut”. Untuk prosedur eksperimen, kaedah Taguchi digunakan dengan menggunakan perisian Minitab dan sejumlah Sembilan (9) set eksperimen dijalankan. Menggunakan tiga (3) ujian; ujian ketegangan, ujian hempapan Charpy, dan mikrostruktur untuk menganalisis dan menyiasat kebolehan kimpalan di antara “keluli tahan karat” dan “keluli lembut”. Hasilnya, semakin tinggi kekuatan ketegangan dan keliatan Charpy, disebabkan peningkatan dalam lebar dan ketebalan nugget kimpalan. Spesimen optimum mempunyai lebar dan ketebalan nugget kimpalan lebih tinggi berbanding spesimen eksperimen. Berdasarkan analisis Taguchi, kombinasi terbaik untuk parameter ialah arus (5.0 kA), tempoh kimpalan (3.0 kitaran) and tekanan (40 psi). Kedudukan parameter yang mempengaruhi eksperimen kimpalan bintik ialah arus, tekanan dan tempoh kimpalan masing-masing. Berdasarkan kepada analisis regresi, persamaan kekuatan ketegangan dan keliatan Charpy telah dijana. Untuk cadangan penambahbaikan, parameter lain seperti diameter elektrod dan tempoh tahanan boleh ditambah dalam eksperimen. Kesimpulannya, analisis Taguchi disahkan dengan eksperimen pengesahan.

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CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

Recently, joining between low carbon steel and stainless steel has hit the spots of the process and construction industries. Low carbon steel for example is mild steel, commonly known have durable and relatively hard materials. For stainless steel, because of high chromium content, it has good corrosion resistance. It also has high strength and ductility, which means an ability to form a desire shape.

The industry out there is constantly seeking construction of equipment and production optimization. For example, in oil and gas industry, resistance spot welding (RSW) is a key technology because the process is fast and can easily weld many different material combinations that are difficult or even impossible to join by other welding techniques. Besides that, many materials can be joined by using RSW, for example stainless steel, aluminum, nickel, copper and titanium. Recently, copper alloys are spot welded commercially to fulfill industries needs.

The project title is "Resistance Spot Welding of Stainless Steel and Mild Steel". The project researched to see the good result of joining and to analyze the design of experiment for optimization parameters in RSW.

1.2 PROBLEM STATEMENTS

The common problems that happen in dissimilar metal joining is the joint not strong, because of Intermetallic Compounds Layer (IMC) occurs. IMC happens because of different chemical composition of materials that have been joining. In order to get rid or reduce IMC, controlling RSW parameters is becoming primary, and by using the DOE for predicting optimize parameter. Controlling RSW parameters need more attention to avoid defects and to produce good weld quality.

1.3 PROJECT OBJECTIVES

a) To investigate Taguchi methods to predict optimizes parameter (welding current, weld time, squeeze time and pressure).
b) To investigate the weldability of stainless steel and mild steel joint (Tensile and Charpy test)

1.4 PROJECT SCOPES

a) Resistance spot welding parameters (Current, Weld Time, Squeeze Time and Pressure)
b) Choosing and preparing the materials (Stainless Steel and Mild Steel)
c) Analyze and investigate the joining results and optimization of parameters by using Taguchi Method.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Welding is a process in which materials of the same fundamental type or class are brought together and caused to join and become one, through the formation of primary (and, occasionally, secondary) chemical bonds under the combined action of heat and pressure (Messler, 1993).

From *The American Heritage Dictionary*, welding function is to join (metals) by applying heat, sometimes with pressure and sometimes with an intermediate or filler metal having a high melting point.

2.2 DISSIMILAR METAL WELDING PROCESS

Commonly, dissimilar metal welding refers to the joining of the metals that has difference on chemical composition, physical and mechanical properties, microstructure, melting point, thermal coefficient and thermal conductivity. In the last few years, new processes have been utilized for dissimilar metal welding such as friction stir welding and laser welding process to join dissimilar metals (Gedney, 2005).

For dissimilar metal welding, a common problem is an intermetallic compound (IMC) is always generated. When a joining process is used, IMC will form in the weld at the joint, and caused to decreased strength and give defects such as cracks (Imaizumi, 1984). A characteristic of IMC formed must be analyzed and investigated in order to minimize their formation, ductility, crack sensitivity and susceptibility to corrosion.

2.3 RESISTANCE SPOT WELDING PROCESSES

From the Resistance spot welding (RSW), this joining method has high efficiency in terms of production method. This is importance to the industries, which can fulfill the needs of automation lines and mass production in industries. Because of the RSW method is flexible, their process is easy to control and not mention their equipment is simple, it efficiently fits for small batch production (Suolaklvenkatu, 2009).

RSW is process, which generate heat through the resistance and to the flow of the electric current in parts being welded. By increasing the contact resistance, the RSW can work properly. The RSW equipment is included with pairs of water-cooled electrodes. This electrodes usually made from copper alloyed, because to increase erosion resistance. This electrode also helps in the process by allow current to the joint and apply pressure to the workpiece (Messler, 1999).

In order to obtain best results in RSW, control the welding parameter become more important. Figure 2.1 below shows the schematic of RSW process.

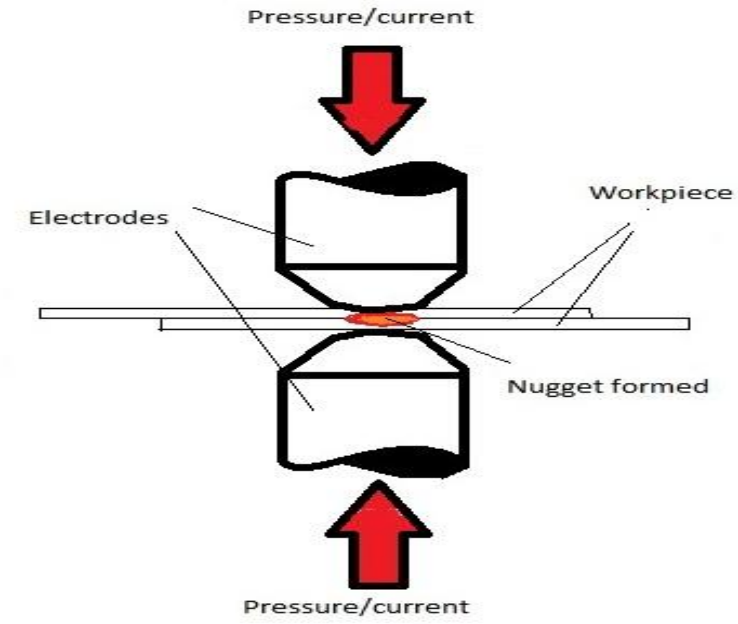

Figure 2.1: Schematic of the Resistance Spot Welding process

2.3.1 PARAMETERS IN RESISTANCE SPOT WELDING

2.3.1.1 Welding Current

Normally, welding current is important parameter in the welding process. Also in RSW, welding current is important in order to determine the heat generation from the process. Usually measured in kilo amperes (kA) and based on *Resistance Welding Manufacture's Association (RWMA)*, the typical amount of current needed to weld carbon steel is about 10 kilo Ampere (kA).

When welding current is increase, the weld formed also increase in diameter. Therefore the strength of the weld also rapidly increases. (Suolaklvenkatu, 2009).

2.3.1.2 Weld Time

In the welding process, the size of welds will increase when the weld time increase. Because of this relation, the heat generation is directly proportional to the welding time. From the process, the heat transfer from the current to the workpiece, usually start from the weld zone. Once the weld forms, the heat transfer to the base metals and surroundings of workpiece.

Welding current and weld time must be controlled efficiently, because if weld time is high enough and weld time is prolonged, expulsion will occur in welds. This accident also can cause the electrodes stick to the workpieces.

2.3.1.3 Electrodes force/ electrodes pressure

Electrodes guide the force or pressure and also weld current to the desired location, which located in interfaces of workpieces. From the force or pressure, it effect on the contact between both of workpieces, which means interfaces of workpieces, region formation of welds occur. If the force or pressure is little, the interfaces required contact between workpieces, and causes the sparking, splashing and rapid wear of electrodes (Suolaklvenkatu, 2009).

2.3.1.4 Squeeze Time

Squeeze time is a time between pressure application and weld to occur. This parameter does not affect the technical properties of the weld. For the process, the squeeze time must be properly adjusted to allow the electrode pressing pressure to the workpiece. After that, welding current is entered and form the welds (Suolaklvenkatu, 2009).

2.3.1.5 Hold Time

Hold time is a time that pressure is maintained after the weld is made. The hold time must be properly adjusted to give time for the molten metal to solidify. Therefore, it stated that the more thick of workpiece, the longer requires for hold time (Suolaklvenkatu, 2009).

2.4 SHEET METAL

Sheet metal is a metal formed into thin and flat pieces. Usually sheet metal will be cut, rolled, bent and other into variety of different shapes. There are many type of metals can be made into sheet metal, such as brass, copper, aluminum, steel and stainless steel. Sheet metal has many applications in industries, such as body car making, aerospace for wing plane and building structure.

2.5 WELDING DEFECTS

Based on American Society of Mechanical Society (ASME), welding defect is any flaw that compromises the usefulness of the finished weldment. Welding defects can be divided into the five factors as shown in Figure 2.2.

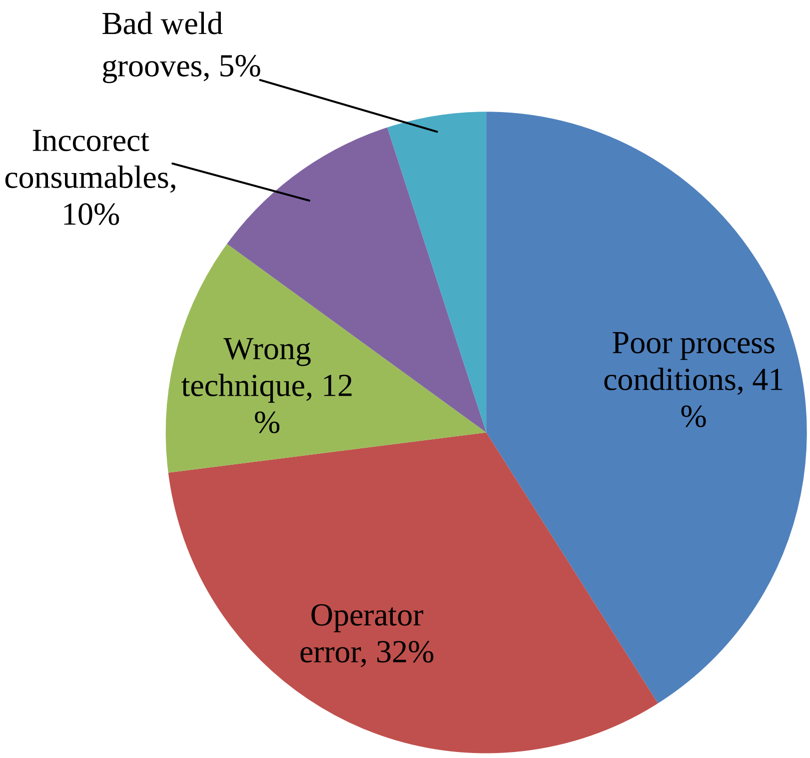

Figure 2.2: Percentage Defects from ASME

Source: Matthews and Clifford (2001)

In the welding process, defects can give bad effect for the weld performance and weld strength when the joints were tested by destructive tests. There are examples for welding defects; porosity, crack, undercut and overlap.

1. Porosity

Basically, porosity is occurring when cavities or pores formed in the welds. Porosity in the welds formed because of the gas and non-metallic material entrapment in molten metal during solidification. In general, poor welding technique cause this defect to happen in the welds. Figure 2.3 shows the porosity defect on the weldment.

The study shows that porosity can be controlled in many ways, for example before start the welding process, proper selection of electrodes, filler materials and selecting welding parameters (B. Leigh and V. Grant. 2009).

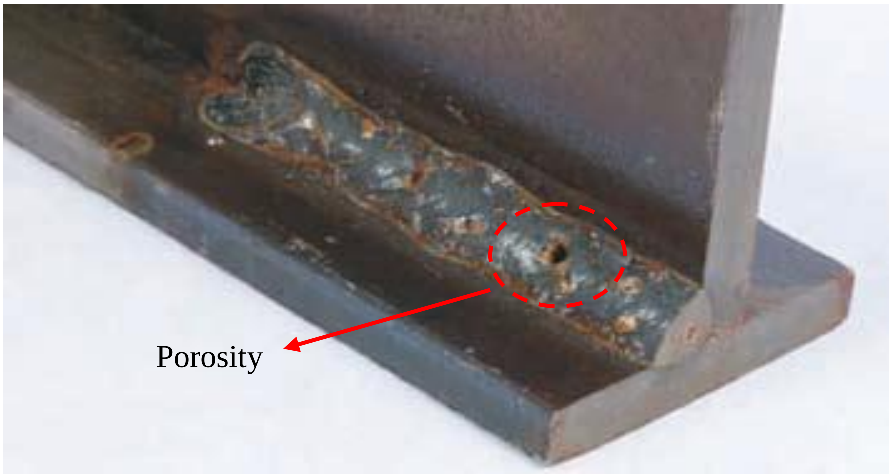

Figure 2.3: Welding defects- Porosity

Source: B. Leigh and V. Grant. (2009)

2. Crack

Cracks that may occur in welded materials are caused generally by many factors and may be classified by shape and position, cracks are classed as planar. This defect is can be classified into several types: longitudinal, transverse, branched and chevron.

After the welding process, the crack must be removed by grinding back. Welders also can repair the welding by welding back (B. Leigh and V. Grant. 2009).

3. Undercut

Undercut can be seen as irregular groove at the welds. Usually, the poor welding technique and selecting parameter cause the undercut to happen at the weld. After the welding process, the cut must be removed by grinding back. Welders also can repair the welding by welding back. Figure 2.4 shows that undercut defect on the weldment (B. Leigh and V. Grant. 2009).

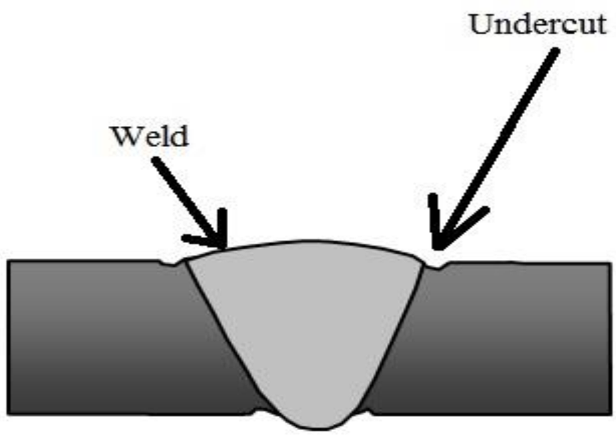

Figure 2.4: Welding defects- Undercut

Source: B. Leigh and V. Grant. (2009)

4. Overlap

Overlap can be defined as an imperfection at the toe or root of a weld caused by metal flowing on to the surface of the parent metal without fusing to it. Basically, overlap caused by contamination, slow travel speed, incorrect welding technique and low current. After the welding process, the overlap must be removed by grinding back (B. Leigh and V. Grant. 2009).

2.6 MASS SPECTROMETER

Spectrometer is one of machine used in determine and identify the chemical compositions of metal or molecule sample. It is an analytical method that measures the charged particle mass to charge ratio. In determining sample, a mass spectrometer changes molecules of sample to ions so that they can be moved and manipulated by magnetic fields and electrical field. The three important components of spectrometer consist:

(a) The ion source: convert gas phase molecules of sample into ions through, for example, electrospray ionization that let the ions turn into gas phase.
(b) The mass analyzer: sort and analyse each ions by the mass and charge by electromagnetic fields
(c) The detector: the ions that have been separated are then measured by the value of quantity indicators. From it, they will provided and the results will be shown on a chart

The spectrometer has practical usage in quantities and qualitative. The machine can also be used in other study in determining physical, chemical or biological properties of any variety of compounds.

2.7 MATERIAL SELECTION

2.7.1 MILD STEEL

In material selection, carbon steels generally are classified by their proportion (by weight) of carbon content. The low the carbon content, usually called as mild steel, which has less than 0.30 % C. Mild steel basically used for industries as a products, for example bolts, plates and nuts.

Secondly, medium-carbon steel has 0.30 to 0.60% C. It generally is used in applications requiring higher strength than is available in low-carbon steels, such as in machinery, automotive and agricultural equipment parts.

Third type is high-carbon steel has more than 0.60% C. Generally, high-carbon steel is used for parts requiring strength, hardness and wear resistance, such as cutting tools, cable, music wire and cutlery.

In carbon steel, the higher content of carbon, it has higher hardness, strength and wear resistance. Table 2.1 shows the carbon steel application in industries (K. Serope and S. Steven. 2006).

Table 2.1: Example of Carbon Steel Application

Types	Application
Low Carbon Steel (Mild Steel)	Common industrial products such as bolts, nuts, sheet, plate and tubes) and for machine components that do not require high strength.
Medium Carbon Steel	Applications requiring higher strength than is available in low-carbon steels, such as in machinery, automotive and agricultural equipment parts.
High Carbon Steel	Generally, high-carbon steel is used for parts requiring strength, hardness and wear resistance, such as cutting tools, cable, music wire and cutlery.

Source: K. Serope and S. Steven (2006)

2.7.2 STAINLESS STEEL

Stainless steels are characterized primarily by their corrosion resistance, high strength and ductility, and high chromium content. They are called stainless because, in the presence of oxygen (air), they develop a thin, hard, adherent film of chromium oxide that protects the metal from corrosion (K. Serope and S. Steven. 2006). Stainless steels generally are divided into five types as shown in Table 2.2.

Table 2.2: Example of Stainless Steel Application

Room- Temperature Mechanical Properties and Typical Applications of Selected Annealed Stainless Steels				
AISI (UNS)	**Ultimate tensile strength (MPa)**	**Yield strength (MPa)**	**Elongation in 50mm (%)**	**Characteristics and typical applications**
303 (S30300)	550-620	240-260	53-50	Screw machine products (shafts, valves, bolts, bushings and nuts) and aircraft fittings (bolts, nuts, rivets, screws, studs).
304 (S30400)	5-620	240-290	60-55	Chemical and food-processing equipment, brewing equipment, cryogenic vessels, gutters, downspouts and flashings.
316 (S31600)	50-590	210-290	60-55	High corrosion resistance and high creep strength, chemical and pulp handling equipment, photographic equipment, brandy vats, fertilizer parts, ketchup-cooking kettles and yeast tubes.
410 (S41000)	480-520	240-310	35-25	Machine parts, pump shafts, bolts, bushings, coal chutes, cutlery, tackle, hardware, jet engine parts, mining machinery, rifle barrels, screws and valves.
416 (S41600)	480-520	275	30-20	Aircraft fittings, bolts nuts, fire extinguisher inserts, rivets and screws.

Source: K. Serope and S. Steven (2006)

2.7.3 JOINING MILD STEEL AND STAINLESS STEEL

From British Stainless Steel Association, welding austenitic stainless steel to carbon and low alloy steels are important and needed method in the various industries such as process and construction industry. Advantage of this joining is the weld form is strong, because of composition of two different materials. Tensile strength and ductility are strong, so the joint will not fail in the weld.

2.8 MECHANICAL TESTING

There are three mechanical testing that will be done on the joints. They are Charpy’s Impact Test, and Tensile Test.

2.8.1 Charpy’s Impact Test

The Charpy’s Impact Test is an impact testing in order to study the behavior of welded objects under dynamic loading. Objective of this test is to determine the behavior of the welds when subjected to high load or impacts and the amount of impact a specimen will absorb before fracture. The relation of the high impact and toughness of the welds also occur from this test. Toughness is defined as the resistance of a metal to fracture after plastic deformation has begun (Messler, 1999).

In this test, a specimen will be struck and broken by a Charpy machine. From this test, the energy absorbed to break the specimen will be adopted. The dimension of Charpy’s test specimens is shown in Figure 2.5.

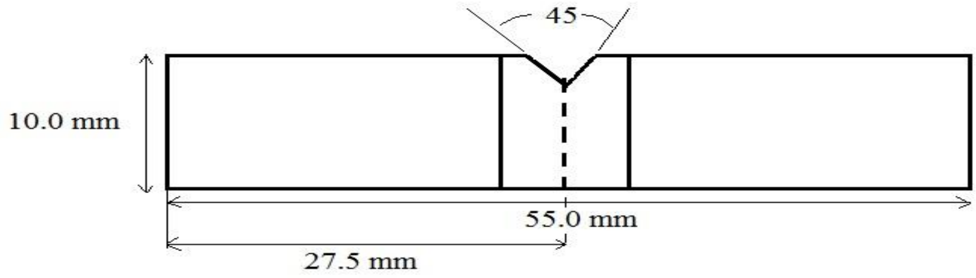

Figure 2.5: Schematic illustrations using Charpy specimens with V-notch

Source: Messler (1999)

2.8.2 Tensile Test

Tensile tests are used to determine the modulus of elasticity, elastic limit, elongation, proportional limit, and reduction in area, tensile strength, yield point, yield strength and other tensile properties.

The stress-strain curve as in Figure 2.6 relates the applied stress to the resulting strain and each material has its own unique stress-strain curve. A typical engineering stress-strain curve is shown below. If the true stress, based on the actual cross-sectional area of the specimen, is used, it is found that the stress-strain curve increases continuously up to fracture.

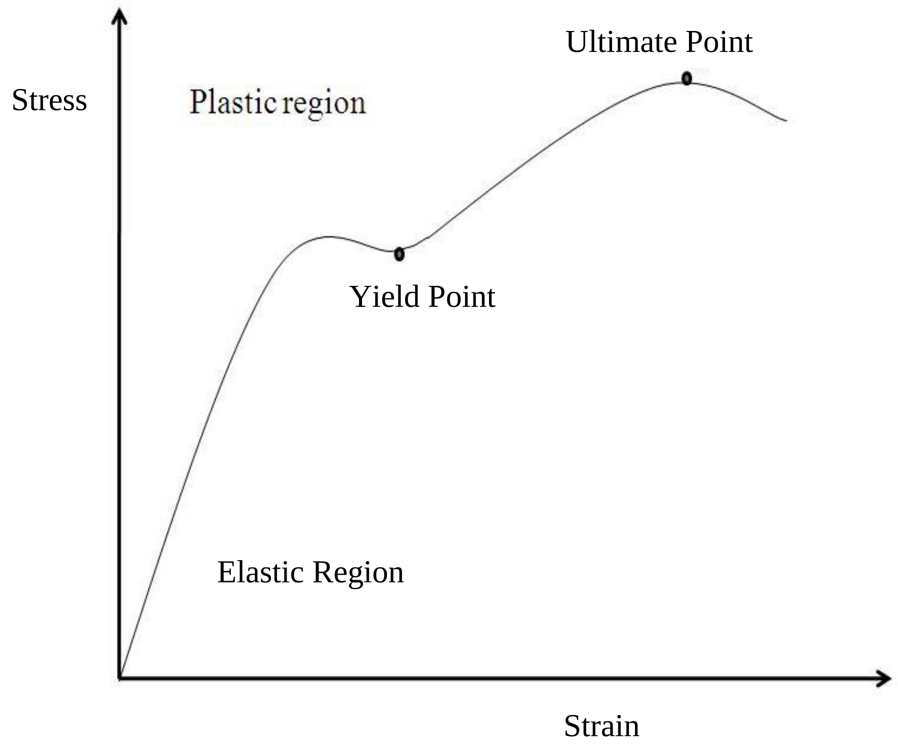

Figure 2.6: Stress-strain curve

Source: J. Haibin *et al*. (2009)

2.9 TAGUCHI METHOD FOR OPTIMIZATION OF PROCESS PARAMETERS

For this project research, the Taguchi Method was selected and analyzed. Taguchi Method was foundered by Dr. Taguchi and states this method is one of the important statistical tools of total quality management for designing high quality systems at lowest cost (P.J. Ross, 2005). Because of this purpose, the cost project can be reduced with high quality of systems.